Unified Cloud and Mixing Parameterizations of the Marine Boundary Layer: EDMF and PDF-Based Cloud Approaches

Joao Teixeira
Jet Propulsion Laboratory, California Institute of Technology
MS 169-237, 4800 Oak Grove Drive
Pasadena, CA 91109
phone: (818) 354-2762 email: teixeira@jpl.nasa.gov

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LONG-TERM GOALS

The long term goals of this effort are (i) the development of a unified parameterization for the marine boundary layer; (ii) the implementation of this new parameterization in the U.S. Navy NAVGEM model; and (iii) the transition of this new version of the NAVGEM model into operations at Fleet Numerical Meteorology and Oceanography Center (FNMOC).

OBJECTIVES

The objectives of this project are: i) to develop a unified parameterization for the Marine Boundary Layer (MBL) and ii) to implement and test this parameterization in the U.S. Navy NAVGEM model. This unified MBL parameterization will be based on two main components: (i) the Eddy-Diffusivity Mass-Flux (EDMF) parameterization of boundary layer mixing; and (ii) the Probability Density Function (PDF) cloud parameterization.

APPROACH

This unified boundary layer parameterization will be based on two main components: (i) the Eddy-Diffusivity Mass-Flux (EDMF) parameterization of turbulence and convective MBL mixing; and (ii) the Probability Density Function (PDF) cloud parameterization. Together these two concepts allow for the unification of MBL parameterization in one single scheme. They also allow for the development of physical parameterizations that lead to a resolution-dependent MBL parameterization that would adjust itself to the horizontal grid resolution.

Key personnel:

- J. Teixeira (JPL/Caltech) uses his expertise in cloud and boundary layer parameterizations to guide the development and implementation of the EDMF/PDF parameterization.
- M. Peng (NRL) uses her expertise in global modeling to assist with the investigations related to NAVGEM within the context of this ONR DRI.
- K. Suselj (UCLA Research Associate) performs the development and implementation of the EDMF parameterization in the NAVGEM model.

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WORK COMPLETED

Evaluation of new EDMF/PDF parameterization in Single Column Model (SCM):
i) New stochastic EDMF shallow convection parameterization was evaluated against observations and LES results for GEWEX Cloud Systems Studies (GCSS) case-studies (e.g. BOMEX, DYCOMS);
ii) New stochastic EDMF shallow convection parameterization was evaluated against observations and LES results for GCSS cloud transition cases – i.e. from stratocumulus to cumulus.

Implementation and evaluation of new EDMF parameterization in NAVGEM SCM:
i) EDMF parameterization was implemented in NAVGEM SCM and tested for GEWEX Cloud Systems Studies (GCSS) case-studies (e.g. BOMEX, DYCOMS).

Implementation and evaluation of new EDMF parameterization in the full global NAVGEM model

RESULTS

Introduction

A parameterization which is suited to represent moist convective boundary layers is implemented in the NAVGEM single-column-model (SCM). The parameterization is based on a stochastic eddy-diffusivity mass-flux (EDMF) approach. In the EDMF framework, turbulent fluxes are calculated as a sum of the down-gradient (eddy-diffusivity) based component and a mass flux component (e.g. Siebesma et al., 2007). The eddy-diffusivity component is based on Louis et al., (1982), as implemented in the current version of the NAVGEM SCM, while the parameterization of the mass-flux component is new in NAVGEM.

The mass-flux component is modeled as a fixed number of steady state plumes. In a dry boundary layer plumes represent the strongest thermals of the flow, and in the cumulus-dominated boundary layer they represent convective clouds. Therefore, the solutions have to account for a realistic representation of condensation within the plumes, and equally important of lateral entrainment into the plumes. We have shown (Sušelj et al. 2012; 2013) that EDMF has the capability to capture the essential features of moist boundary layers, ranging from stratocumulus to shallow-cumulus regimes.

The EDMF parameterization developed and tested in the NAVGEM SCM framework (see ONR report, 2012) is improved by tuning the parameters defining the surface properties of the mass-flux and the entrainment rate, so that three types of surface forced boundary layers are well represented: dry convective boundary layer, marine-shallow convection, and continental shallow convection.

EDMF is also implemented in the three-dimensional version of NAVGEM and the results are evaluated against analysis and observations. These results show that EDMF in NAVGEM improves (with respect to the control version which is the version of NAVGEM without EDMF) the forecast of most of the relevant atmospheric parameters.

NAVGEM model results

We show selected results from the SCM model for marine (BOMEX) and continental (ARM) shallow convection cases. The SCM results are compared to the Large-Eddy-Simulation (LES) results from Siebesma (2003) for the BOMEX case and the LES results used in Sušelj et al. (2013) for the ARM

case. For the SCM we use 91 vertical levels that correspond to the ECMWF vertical levels. The forcing and the initial conditions for the SCM are defined the same way as for the LES simulations. The three-dimensional results are obtained by running NAVGEM in a forecast mode. We compare the forecast results of the control and EDMF version of the model against analysis.

a) SCM model results

Fig. 1 compares the moist conserved variables and the turbulent fluxes from the EDMF SCM and an ensemble of LES. In the SCM, the sub-cloud layer (below around 600 m) is almost well mixed which is in agreement with the LES results. Both moist conserved variables have a slight kink at the surface. The reason for that is the strong peak of the turbulent flux from the eddy-diffusivity part of the parameterization. The moist conserved variables from the SCM agree relatively well with the LES results in the cumulus-dominated layer (from around 600 m to 2000 m). Compared to the LES, the lower part of the cloud layer is slightly drier and the upper part is slightly moister. This is a consequence of an unrealistic peak of the turbulent fluxes of total water mixing ratio in the lower part of the cloud layer in the SCM. The reason that SCM represents the profiles of moist conserved variables well is its realistic representation of turbulent fluxes (lower panel on Fig. 1).

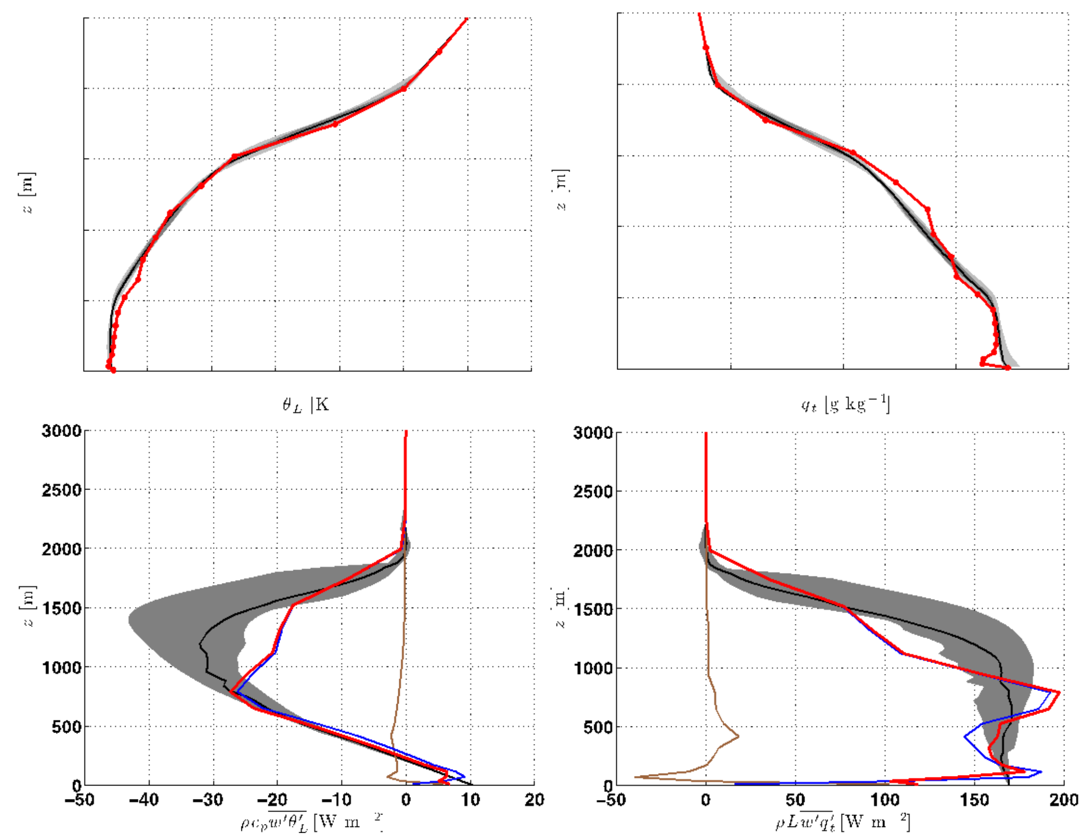

Fig.1: BOMEX case. Profiles of moist conserved variables (upper left: liquid water potential temperature, upper right: total water mixing ratio) and turbulent fluxes (lower left: sensible, lower right: latent heat flux) averaged between second and third simulation hour. The red lines represent the SCM results (circles denote the vertical levels of the model) and the black lines the LES mean. The grey shading is the interquartile range from LES. In the lower panel the brown line represents the eddy-diffusivity (ED) part of the turbulent flux, blue the mass-flux (MF) part and red the total flux (ED + MF).

The ARM case is an example of non-stationary convection over land characterized by time-varying surface latent and sensible heat fluxes and the gradual growth of the boundary layer, which is initially dry, and then transitions to a cloud-topped boundary layer. Fig. 2 shows hourly averaged vertical profiles of moist conserved variables and the corresponding turbulent fluxes every two hours through the simulation time. The boundary layer deepens over the course of the day and is well mixed and topped by a shallow cumulus layer after the fifth simulation hour. The SCM represents the deepening of the boundary layer well. The profiles of liquid water potential temperature agree well with the LES results. In the SCM, the well mixed boundary layer is more moist than in the LES results and consequently the cumulus dominated cloud layer is drier compared to the LES results. The turbulent fluxes of moist conserved variables are reasonably well represented. In the first simulation hours the turbulent fluxes tend to reach zero values at high altitudes, in agreement with higher cloud tops.

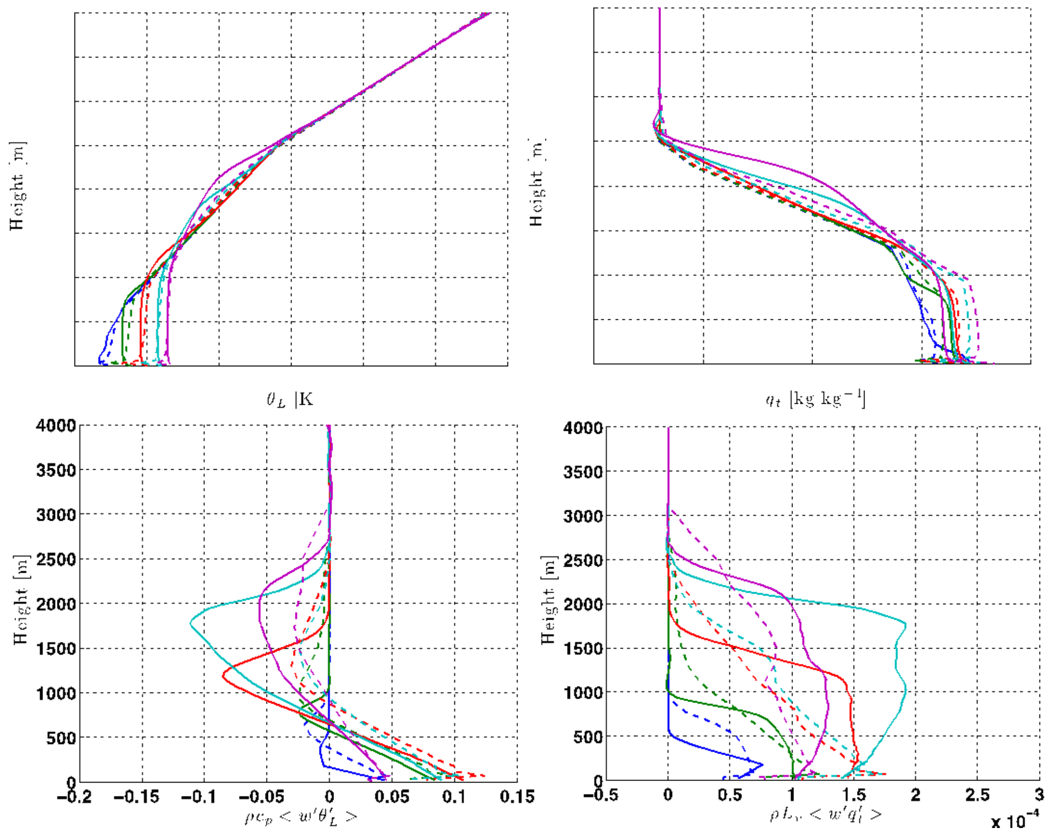

Fig. 2: ARM case. Profiles of moist conserved variables (upper panel) and the corresponding turbulent fluxes (lower panel) from SCM (dashed lines) and LES (full lines). The results are hourly averaged values centered on the third (dark blue), fifth (green), seventh (red), ninth (light blue) and eleventh (violet) simulation hours.

b) Three-dimensional NAVGEM model results

To investigate whether EDMF in NAVGEM improves the forecast, one month (March 2013) of forecasts for up to 5 days (120 forecast hours) have been computed with the EDMF and control versions of NAVGEM and compared against the analysis. Fig. 3 shows the anomaly correlation of the geopotential height at 500 hPa for the northern and southern hemisphere and compares it to the anomaly correlation of the NCEP Global Forecast System (GFS). The EDMF NAVGEM forecast

results are significantly better than the results from the control version in both the northern and southern hemisphere. With a longer forecast time the improvement of the EDMF over control version of NAVGEM becomes more obvious. The results from the EDMF version of NAVGEM are closer to GFS than the control version.

Many other forecast variables show a significant improvement with the EDMF parameterization implemented in the full three-dimensional version of NAVGEM: In particular variables associated with moist thermodynamics such as temperature and water vapor content, with the positive effects of EDMF being felt throughout the troposphere. The new version of NAVGEM with EDMF is currently being tested in a quasi-operational mode at NRL and FNMOC.

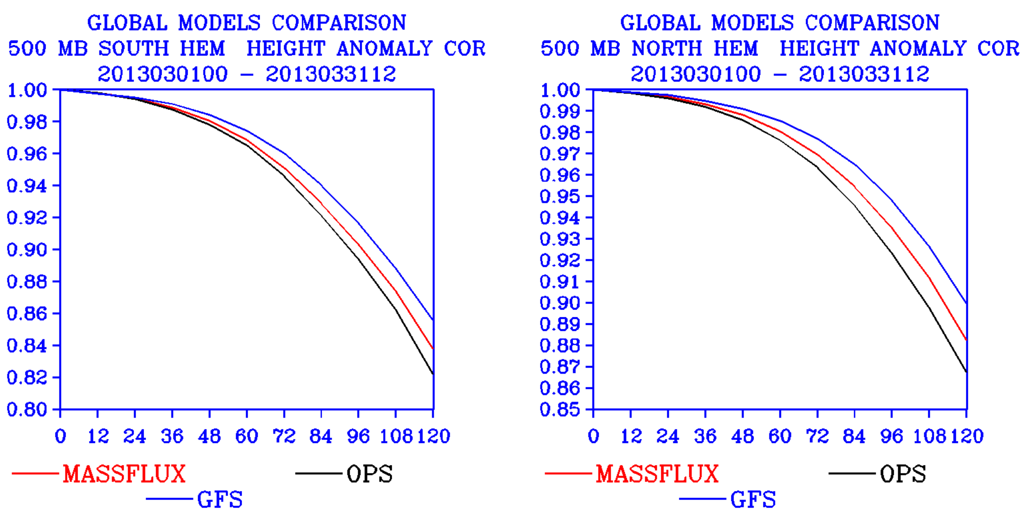

Fig.3: The anomaly correlation for the geopotential height at 500 hPa for the northern (left) and southern (right) hemisphere as a function of forecast time for NAVGEM (black line for control and red line for EDMF) and for the GFS model. The GFS model is shown as a benchmark.

Conclusions

The EDMF parameterization in NAVGEM complements the boundary layer parameterization by simulating surface forced moist convection. We show examples of SCM test cases, which cannot be reasonably simulated with the control NAVGEM SCM. The EDMF parameterization implemented in the full three-dimensional forecast NAVGEM model significantly improves the overall forecasts.

IMPACT/APPLICATIONS

As shown above the EDMF parameterization has a key impact on the weather prediction capabilities of the U.S. Navy with the operational implementation of this new parameterization in the NAVGEM model. In addition it will be the first time that a unified parameterization of the marine boundary layer has ever been developed and implemented in a global weather prediction model.

TRANSITIONS

The new EDMF parameterization is currently being tested in the NAVGEM forecast system in a quasi-operational mode at NRL and FNMOC.

RELATED PROJECTS

This project is part of the "Unified Physical Parameterizations for Seasonal Prediction" Departmental Research Initiative.

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